Commercial Building Planning and Retrofitting Strategy for Grid Services

Preprint

Weijia Liu,[1] Yiyun Yao,[1] Rishabh Jain,[1] Richard Mrlik,[2] and Zander Mrlik[2]

1 National Renewable Energy Laboratory
2 Intertie Incorporated

Presented at the IEEE PES T&D Conference and Exhibition
New Orleans, Louisiana
April 25–28, 2022

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

Conference Paper
NREL/CP-5D00-80640
May 2022

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Commercial Building Planning and Retrofitting Strategy for Grid Services

Preprint

Weijia Liu,[1] Yiyun Yao,[1] Rishabh Jain,[1] Richard Mrlik,[2] and Zander Mrlik[2]

1 National Renewable Energy Laboratory
2 Intertie Incorporated

Suggested Citation
Liu, Weijia, Yiyun Yao, Rishabh Jain, Richard Mrlik, and Zander Mrlik. 2022. *Commercial Building Planning and Retrofitting Strategy for Grid Services: Preprint*. Golden, CO: National Renewable Energy Laboratory. NREL/CP-5D00-80640. https://www.nrel.gov/docs/fy22osti/80640.pdf.

© 2022 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Conference Paper
NREL/CP-5D00-80640
May 2022

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by Shell as part of the Shell GameChanger program. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

U.S. Department of Energy (DOE) reports produced after 1991 and a growing number of pre-1991 documents are available free via www.OSTI.gov.

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

NREL prints on paper that contains recycled content.

Commercial Building Planning and Retrofitting Strategy for Grid Services

Weijia Liu[1], Yiyun Yao[1], Rishabh Jain[1], Richard Mrlik[2], Zander Mrlik[2]

[1]National Renewable Energy Laboratory
Golden, CO, U.S.A.
{weijia.liu; yiyun.yao; rishabh.jain}@nrel.gov

[2]Intertie Incorporated
Sausalito, CA, U.S.A.
{richard; zander}@intertie.com

Abstract — **The increasing integration of distributed energy resources (DERs) plays an important role in improving energy consumption efficiency. In September 2020, the Federal Energy Regulatory Commission (FERC) approved Order 2222 that opens wholesale electricity markets to small capacity DERs. The benefit from this new FERC Order 2222 is that DERs, such as rooftop solar panels and batteries, will be able to participate in regional electricity markets and provide grid services. Meanwhile, the planning and operation strategies of DERs are facing new challenges to account for the impact of the wholesale market with numerous uncertainty factors. Therefore, in this paper, we propose a new planning and retrofitting model for long-term commercial building that considers both DER investment and market participation. Specifically, we explore the capability of implementing DERs for grid services. The effectiveness of the proposed model is validated using real-world data. Simulation results also validate that participating in grid services can significantly increase revenues through appropriate building energy management and shorten the payback period of DER investments.**

Index Terms -- **Building energy management, distributed energy resources (DERs), electricity market, frequency regulation, grid services, power system planning**

I. Introduction

Across the United States, buildings (residential, commercial, and industrial) use a large share of the total energy consumption, according to the U.S. Energy Information Administration [1]; therefore, improving the energy consumption efficiency of buildings will significantly contribute towards achieving the green energy transition target [2]; and has always been of great significance for the power industry. The rapid growth of distributed energy resources (DERs) is being witnessed across the globe [3], and customers have been granted the capabilities to reduce energy bills, reduce their carbon footprint, and flexibly control their consumption behaviors. Photovoltaic (PV) panels and battery energy storage system (BESS) are popular DER solutions to reducing building energy bills. Another option to improve building energy efficiency is the introduction of active load management, which can be achieved by adding controllers/inverters to the original uncontrollable load. In the past few years, the optimal DER planning for buildings has been comprehensively investigated. For example, a techno-economic analysis of PV and BESS planning for building energy management is developed in [4]; a multi-objective planning model for PV and BESS investment in residential buildings is developed in [5]; the optimal sizing of DERs in commercial buildings is studied in [6] where peak load management is considered. However, it is also shown in existing studies that the DER integration is constrained because of the high capital costs and limited revenues based on existing regulations.

In this context, employing DER capabilities to provide grid services, especially transmission grid services, is becoming a popular idea. In September 2020, the Federal Energy Regulatory Commission (FERC) approved a new rule, Order 2222, that enables DER aggregators to participate in wholesale markets [7]. Previously, DER aggregators had to meet the minimum entry capacity of 0.5 MW or larger to qualify for the wholesale market [8] [9]. Order 2222 has reduced the capacity barriers to no more than 0.1 MW, which encourages smaller DER sites and aggregators to enter the wholesale market. The order is expected to boost the integration of DERs by providing more profitable business models. Participating in the wholesale market, however, could also introduce new planning and operating challenges for DER aggregators. The revenues generated by DERs are influenced by many uncertain factors including wholesale market price, market programs, DER operating constraints, and DER lifespan; therefore, DER planning and operating strategies that consider grid services and wholesale market uncertainties are in urgent demand to fully exploit the capabilities of DERs and to equip aggregators with the necessary tools to take advantage of the new FERC Order 2222.

To bridge this gap, this paper develops a planning and retrofitting model for commercial building aggregators to optimize the resource mix for the upcoming wholesale market challenges. DER planning options such as PV and BESS investment and controllable load retrofits made are to accommodate the planning need in general. Both traditional distribution grid services (such as peak load management) and market-based transmission grid services (such as frequency regulation) are considered. The contribution of this paper is to evaluate the impact of the new FERC

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by Shell as part of the Shell GameChanger program. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Order 2222 on building sector and consider wholesale market in the DER planning phase. We test our model using practical data to provide reasonable decision-making support for Intertie Incorporated in California, U.S.

The rest of this paper is organized as follows. Section II briefly reviews the commercial building planning and retrofitting options and discusses the grid service options. Section III develops a planning and retrofitting model based on the identified resources and grid services. Section IV demonstrates the simulation results using real-world data to validate the effectiveness of the proposed model. Section V concludes the paper.

II. Problem Overview

A. Planning and Retrofitting Options

A multitude of factors like location, load type, available DER technologies, costs, and use-cases of the customer present a wide variety of options when designing/upgrading a system. Often, many of the use-cases may be addressed by retrofitting the existing system load. In other words, the challenge of planning, designing, and/or retrofitting any system can be presented as a comprehensive optimization problem. Therefore, the investment in PV panels and BESS and the retrofit of controllable load are considered in this study. The building energy management with these planning and retrofitting options is illustrated in Fig. 1. Commercial buildings may also be interested in backup power supplies to enhance reliability in event of an outage, which will not be elaborated in this study because of space limit. In this paper, we assume the planning and operation of a commercial building are managed by a building aggregator, which can act as a market participant in the wholesale market to submit bids/offers for building load and DERs.

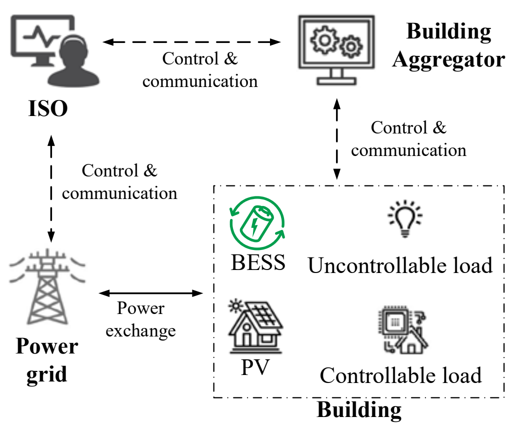

Fig. 1 An illustration of building energy management

B. Targeted Grid Services

Although FERC Order 2222 highlighted that aggregated DERs can participate in ISO markets, building aggregators might not always qualify for all available market products because of technical limitations. In this study, we consider the following three grid services:

- **Peak load management**: The capacity of the service transformer and associated compensation devices is primarily determined by the peak load of a commercial building. Limiting the peak load will help utility systems and building aggregators to defer grid upgrades and new investments. Here, we consider peak load management as a planning constraint where the building aggregator agrees to limit the peak load at a predefined level with no extra compensation.
- **Demand response/shifting**: Demand response is a well-defined service where the load will be curtailed at the requested period to help maintain the bulk system power balance. Demand shifting appears to be a more interesting option that also increases the power load to level off peak-valley variations. This can be extremely helpful to deal with the "duck curve" experienced in California. Typically, the demand response/shifting scheme offers a fixed compensation price through a long-term contract that specifies the total number and frequency of service calls during the contract period.
- **Frequency regulation**: Frequency regulation is a market product that will be open to aggregated DERs. Inverter-based DERs such as BESS can promptly respond to frequency regulation (i.e., automatic generation control) signals. The success of the Tesla battery facility in South Australia has demonstrated that these inverter-based resources outperform traditional generators in terms of power system frequency control [10]; hence, we assume that the BESS units are eligible to provide frequency regulation services. Note that PV panels are not considered for frequency regulation because they typically operate using maximum power point tracking and curtailing PV generation is generally not desired. The traditional building loads usually have a very large time constant and slow responsive speed, making them unqualified for frequency regulation as well.

Another challenging issue to be addressed is the mitigation of "double counting," which means that DERs should not be compensated in multiple markets by providing one service. In the aforementioned three services, the demand response/shifting and frequency regulation could lead to double counting. For simplicity, the frequency regulation service will be disabled when the demand response/shifting service is being requested.

C. Uncertainty Management

Several uncertainty factors should be considered when deciding the optimal planning and retrofit solutions for commercial buildings, including but not limited to:

- Building load growth rate (both peak load and energy demand), load consumption pattern, and profile
- PV generation capability
- Grid service uncertainty caused by irregular grid service request calls, fluctuating compensation price, etc.

Moreover, these uncertainty factors are correlated and difficult to model using probabilistic analysis (e.g., demand response/shifting service is usually requested during load peak hours); therefore, we employ a scenario-based stochastic optimization approach to manage uncertainty. The scenarios will be generated using correlated historical time-series data, and scenario reduction techniques will be employed to shortlist representative scenarios to relieve the computational burden.

III. Planning and Retrofit Model

A. Objective Function

Building planning and retrofitting targets are aimed at

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

reducing the total energy bill considering investment cost, operating cost, and grid service rewards, as shown in (1).

$$\min\ C_{\text{total}} = C_{\text{inv}} + \sum_s \beta_s (C_{\text{op}}^s - R_{\text{ms}}^s + C_{\text{pen}}^s) \qquad (1)$$

where C_{total} and C_{inv} denote the total cost and investment planning cost, respectively; and C_{op}^s, R_{ms}^s, and C_{pen}^s denote the operating cost, grid service income, and penalty for failing to provide the requested grid services in scenario s, respectively. β_s denotes the weight of scenario s.

Assume that all the investments are made at the beginning of the planning period. Given a planning period of k years, the annuity of investment (i.e., equal annual payments based on interest rate and planning period) is calculated as:

$$C_{\text{inv}} = \frac{\eta(1+\eta)^{k-1}}{(1+\eta)^{k-1}} (C_{\text{PV,inv}} + C_{\text{ESS,inv}} + C_{\text{CL,inv}}) \qquad (2)$$

where η denotes the interest rate; and $C_{PV,inv}$, $C_{ESS,inv}$, and $C_{CL,inv}$ denote the investment cost of PV, BESS, and controllable load, respectively.

The operating cost includes the energy procurement cost, generation revenue (when generation is redundant), and the maintenance costs of the PV and ESS.

$$C_{\text{op}}^s = \sum_t \left(\lambda_{\text{TOU}}^{s,t} P_{\text{im}}^{s,t} - \lambda_{\text{mcp}}^{s,t} P_{\text{ex}}^{s,t}\right) + C_{\text{op,ESS}} + C_{\text{op,PV}}\ , \forall s \qquad (3)$$

where $\lambda_{\text{TOU}}^{s,t}$, $\lambda_{\text{mcp}}^{s,t}$, $P_{\text{im}}^{s,t}$, and $P_{\text{ex}}^{s,t}$ denote the time-of-use (TOU) energy price, market clearing price, procured power, and exported power at time t, respectively. $C_{\text{op,ESS}}$ and $C_{\text{op,PV}}$ denote the maintenance costs of PV and ESS, respectively. Note that the (peak) demand charge is not a variable in this planning model because the peak load capacity is a fixed value.

The income for grid services comes from two parts: demand response and frequency regulation, as shown in (4).

$$R_{\text{ms}}^s = \beta_{\text{DR}} P_{\text{DR,cap}} + \sum_t \left(\lambda_{\text{RU}}^{s,t} P_{\text{RU}}^{s,t} + \lambda_{\text{RD}}^{s,t} P_{\text{RD}}^{s,t}\right)\ , \forall s \qquad (4)$$

where β_{DR} denotes the demand response compensation price, and $P_{\text{DR,cap}}$ denotes the demand response capacity. Note that β_{DR} and $P_{\text{DR,cap}}$ are not scenario-dependent. $\lambda_{\text{RU}}^{s,t}$, $\lambda_{\text{RD}}^{s,t}$, $P_{\text{RU}}^{s,t}$, and $P_{\text{RD}}^{s,t}$ denote the regulation-up capacity price, regulation-down capacity price, regulation-up capacity, and regulation-down capacity, respectively. The regulation mileage payment is ignored here for simplicity.

Corresponding to the grid service incomes, failing to provide the requested service will be subject to penalties as shown in (5).

$$C_{\text{pen}}^s = \sum_t (\beta_{\text{DR,p}} P_{\text{DR,f}}^{s,t} + \beta_{\text{RU,p}} P_{\text{RU,f}}^{s,t} + \beta_{\text{RD,p}} P_{\text{RD,f}}^{s,t})\ , \forall s \qquad (5)$$

where $\beta_{\text{DR,p}}$, $\beta_{\text{RU,p}}$, and $\beta_{\text{RD,p}}$ denote the penalty cost for demand response, regulation-up, and regulation-down, respectively. $P_{\text{DR,f}}^{s,t}$, $P_{\text{RU,f}}^{s,t}$, and $P_{\text{RD,f}}^{s,t}$ denote the capacities of demand response, regulation-up, and regulation-down that failed to fulfill the service requirement, respectively.

B. Constraints

The planning problem should account for constraints associated with the PV, ESS, controllable load, and power balance.

1) PV constraints:

$$C_{\text{PV,inv}} = \alpha_{\text{PV,inv}} P_{\text{PV,inv}} \qquad (6)$$

$$C_{\text{op,PV}} = \alpha_{\text{PV,op}} P_{\text{PV,inv}} \qquad (7)$$

$$P_{\text{PV}}^{s,t} \le \mu_{\text{PV}}^{s,t} P_{\text{PV,inv}}\ , \forall s, t \qquad (8)$$

$$P_{\text{PV,inv}} \le P_{\text{PV,inv}}^{\max} \qquad (9)$$

where equations (6) and (7) calculate the PV investment cost and annual maintenance cost, PV generation is constrained by (8), and PV investment is constrained by (9). $\alpha_{\text{PV,inv}}$ and $\alpha_{\text{PV,op}}$ denote the PV investment and maintenance cost coefficients, respectively. $P_{\text{PV,inv}}$ denotes the PV investment capacity, and $P_{\text{PV,inv}}^{\max}$ is the maximum investment capacity specified by the aggregator. $P_{\text{PV}}^{s,t}$ and $\mu_{\text{PV}}^{s,t}$ denotes the PV generation and maximum generation capability at time t in scenario s, respectively.

2) ESS constraints:

$$C_{\text{ESS,inv}} = \alpha_{\text{ESS,inv}} E_{\text{ESS,inv}} \qquad (10)$$

$$C_{\text{op,ESS}} = \alpha_{\text{ESS,op}} E_{\text{ESS,inv}} \qquad (11)$$

$$\sigma_{\text{ESS}}^{s,t+1} = \sigma_{\text{ESS}}^{s,t} + \left(\eta_{\text{ESS,c}} P_{\text{ESS,c}}^{s,t} - \frac{1}{\eta_{\text{ESS,d}}} P_{\text{ESS,d}}^{s,t}\right)\ , \forall s, t \qquad (12)$$

$$\sigma_{\text{ESS}}^{\min} E_{\text{ESS,inv}} \le \sigma_{\text{ESS}}^{s,t} \le \sigma_{\text{ESS}}^{\max} E_{\text{ESS,inv}}\ , \forall s, t \qquad (13)$$

$$0 \le P_{\text{ESS,c}}^{s,t} \le P_{\text{ESS,c}}^{\max} E_{\text{ESS,inv}}\ , \forall s, t \qquad (14)$$

$$0 \le P_{\text{ESS,d}}^{s,t} \le P_{\text{ESS,d}}^{\max} E_{\text{ESS,inv}}\ , \forall s, t \qquad (15)$$

$$\sum_t (\eta_{\text{ESS,c}} P_{\text{ESS,c}}^{s,t} - \frac{1}{\eta_{\text{ESS,d}}} P_{\text{ESS,d}}^{s,t}) = 0\ , \forall s \qquad (16)$$

$$E_{\text{ESS,inv}} \le E_{\text{ESS,inv}}^{\max} \qquad (17)$$

where equations (10) and (11) calculate the ESS investment cost and annual maintenance cost. The ESS stored energy is calculated by (12) and constrained by (13). The ESS charging and discharging power are constrained by (14) and (15), respectively. Constraint (16) enforces that in each scenario, the net energy generation/consumption of the ESS remains zero to avoid exhausting the ESS capability. The ESS investment is constrained by (17). $\alpha_{\text{ESS,inv}}$ and $\alpha_{\text{ESS,op}}$ denote the ESS investment and maintenance cost coefficients, respectively. $E_{\text{ESS,inv}}$ denotes the ESS investment capacity and $E_{\text{ESS,inv}}^{\max}$ is the maximum investment capacity specified by the aggregator. $P_{\text{ESS,c}}^{s,t}$ and $P_{\text{ESS,d}}^{s,t}$ are the ESS charging and discharging powers, whereas $\eta_{\text{ESS,c}}$ and $\eta_{\text{ESS,d}}$ represent the charging and discharging efficiencies, respectively. $\sigma_{\text{ESS}}^{s,t}$ denotes the energy stored in the ESS at time t in scenario s, where $\sigma_{\text{ESS}}^{\max}$ and $\sigma_{\text{ESS}}^{\min}$ denote the maximum and minimum energy storage ratio, respectively. Similarly, $P_{\text{ESS,c}}^{\max}$ and $P_{\text{ESS,d}}^{\max}$ denote the maximum charging and discharging power w.r.t. $E_{\text{ESS,inv}}$, respectively.

3) Controllable load constraints:

$$C_{\text{CL,inv}} = \alpha_{\text{CL,inv}} P_{\text{CL,inv}} \qquad (18)$$

$$\gamma_{\text{CL}} P_{\text{CL,inv}} \le P_{\text{CL}}^{s,t} \le P_{\text{CL,inv}} \qquad (19)$$

$$\tau_{\text{CL}} P_{\text{CL,inv}} \le \sum_t P_{\text{CL}}^{s,t}\ , \forall s \qquad (20)$$

$$P_{\text{CL,inv}} \le P_{\text{CL,inv}}^{\max} \qquad (21)$$

where equation (18) calculates the controllable load investment cost. The controllable load power is constrained by (19), and the total controllable energy consumption is constrained by (20). The controllable load investment is constrained by (1). $\alpha_{\text{CL,inv}}$ denotes the controllable load investment cost coefficient. $P_{\text{CL,inv}}$ denotes the ESS investment capacity and $P_{\text{CL,inv}}^{\max}$ is the maximum investment capacity specified by the aggregator. $P_{\text{CL}}^{s,t}$ is the controllable load power at time t in scenario s, whereas γ_{CL}

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

represents the minimum load consumption w.r.t. $P_{\mathrm{CL,inv}}$. In each scenario, the total energy consumption of the controllable load must meet a minimum requirement, as indicated by τ_{CL}.

4) Power balance constraints:

$$\begin{aligned} P_{\mathrm{im}}^{s,t} - P_{\mathrm{ex}}^{s,t} = {} & P_{\mathrm{ESS,c}}^{s,t} - P_{\mathrm{ESS,d}}^{s,t} + P_{\mathrm{CL}}^{s,t} + P_{\mathrm{NCL}}^{s,t} - P_{\mathrm{PV}}^{s,t} \\ & + \rho_{\mathrm{DR}}^{s,t}\left(P_{\mathrm{DR,cap}} - P_{\mathrm{DR,f}}^{s,t}\right) + \rho_{\mathrm{RU}}^{s,t}\left(P_{\mathrm{RU}}^{s,t} - P_{\mathrm{RU,f}}^{s,t}\right) \\ & - \rho_{\mathrm{RD}}^{s,t}\left(P_{\mathrm{RD}}^{s,t} - P_{\mathrm{RD,f}}^{s,t}\right) \quad ,\forall s,t \end{aligned} \tag{22}$$

$$P_{\mathrm{im}}^{s,t} - P_{\mathrm{ex}}^{s,t} \le P_{\mathrm{cap}} \quad ,\forall s,t \tag{23}$$

$$0 \le P_{\mathrm{RU}}^{s,t} \le P_{\mathrm{ESS,d}}^{\max} E_{\mathrm{ESS,inv}} + P_{\mathrm{ESS,c}}^{s,t} - P_{\mathrm{ESS,d}}^{s,t} \quad ,\forall s,t \tag{24}$$

$$0 \le P_{\mathrm{RD}}^{s,t} \le P_{\mathrm{ESS,c}}^{\max} E_{\mathrm{ESS,inv}} + P_{\mathrm{ESS,d}}^{s,t} - P_{\mathrm{ESS,c}}^{s,t} \quad ,\forall s,t \tag{25}$$

where equation (22) calculates the power balance of the aggregator concerned. Constraint (23) limits the net power import/export of the aggregator to denote the peak load management requirement. Constraints (24) and (25) enforce that the frequency regulation capacity cannot exceed the BESS capacity. $P_{\mathrm{NCL}}^{s,t}$ denotes the noncontrollable load; and $\rho_{\mathrm{DR}}^{s,t}$, $\rho_{\mathrm{RU}}^{s,t}$, and $\rho_{\mathrm{RD}}^{s,t}$ indicate whether the corresponding service is requested at that period. For example, $\rho_{\mathrm{DR}}^{s,t} = 1$ means that the demand response service is requested at time *t* in scenario *s*. P_{cap} denotes the peak load.

IV. Case Study

A. Simulation Setup

The planning and retrofit model presented in Section III is a linear programming model, which is solved using the open-source coin-or linear programming solver [11] on the open-source optimization platform OR-Tools [12]. One-year historical data are employed to generate the scenarios for the stochastic optimization, where each scenario contains 24 consecutive hours. Three representative weeks (one winter peak week, one summer peak week, and one spring/fall valley week) are selected in this case study, resulting in 21 scenarios in total.

The PV generation data are derived from [13], the PV and ESS investment cost data are derived from [14], and the market price data are derived from the California ISO [15]. Other inputs such as load data are obtained from the historical record from Intertie Incorporated. The original peak load capacity before planning is 500 kW. A summary of the test data is listed in Table I, and some sample data series are illustrated in Fig. 2.

TABLE I Test Data for Building Planning and Retrofitting

k	10 (yrs)	η	5.0%
$\alpha_{\mathrm{PV,inv}}$	1.64 ($/W)	$\alpha_{\mathrm{PV,op}}$	2.5%
$\alpha_{\mathrm{ESS,inv}}$	0.71 ($/Wh)	$\alpha_{\mathrm{ESS,op}}$	2.5%
$\alpha_{\mathrm{CL,inv}}$	0.25 ($/W)	$\sigma_{\mathrm{ESS}}^{\max}$	95%
$\sigma_{\mathrm{ESS}}^{\min}$	5%	$\eta_{\mathrm{ESS,c}}, \eta_{\mathrm{ESS,d}}$	98%
$P_{\mathrm{ESS,c}}^{\max}, P_{\mathrm{ESS,d}}^{\max}$	50%	$P_{\mathrm{PV,inv}}^{\max}$	500 kW
$E_{\mathrm{ESS,inv}}^{\max}$	300 kWh	$P_{\mathrm{CL,inv}}^{\max}$	250 kW
γ_{CL}	20%	τ_{CL}	12 (hrs)
β_{DR}	100 ($/kW·yr)	$\beta_{\mathrm{DR,p}}$	0.5 ($/kW)
$\beta_{\mathrm{RU,p}}, \beta_{\mathrm{RD,p}}$	1.0 ($/kW)		

B. Numerical Results

The following cases are simulated to evaluate the optimal building planning schemes with different market participation options. The peak load constraint will enforce the peak load not exceeding 300 kW compared to the original 500 kW.

Case 1: Planning considering peak load as a constraint;
Case 2: Planning considering peak load as a constraint and demand response as a grid service;
Case 3: Planning considering peak load as a constraint and both demand response and regulation services.

The planning and retrofitting solutions for these three cases are listed in Table II. To reiterate from Section II, planning for peak load manage-ment doesn't consider backup power as a resource. Case 1 considers only the peak load constraint, thus the optimal solution is to invest in PV panels to offset the peak load consumption. Moreover, 250 kW of load will be retrofitted to become controllable to reduce the load peak. Compared to Case 1, Case 2 enables building load to perform demand response. As shown in Table II, Case 2 will provide 64.6 kW of demand response capacity. This additional demand response capacity could put an extra burden on the building aggregator at load peak hours to maintain a 300 kW peak demand, thus the invested PV capacity in Case 2 is also larger than that in Case 1 to deal with the uncertain demand response requests. Note that although PV investment is higher in Case 2, the revenue gained from the demand response service manages to reduce the annual energy cost by approximately ~$750 compared to Case 1. In other words, participating in grid services can help building aggregators offset DER investment costs and create additional revenues.

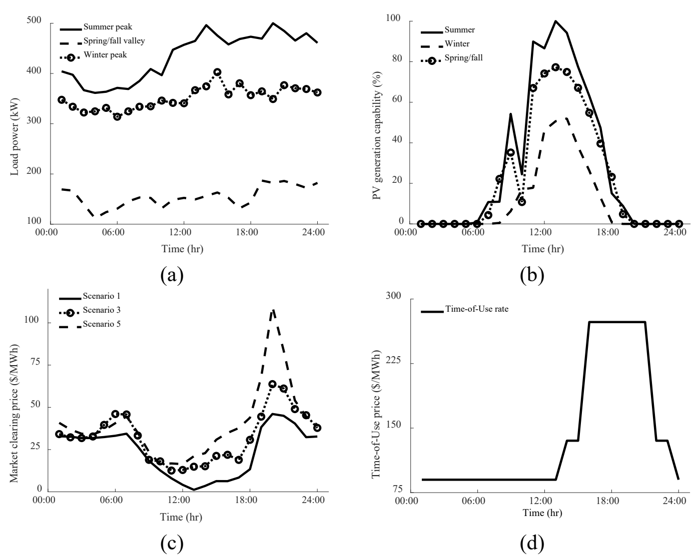

Fig. 2 Sample data series: (a) load profile of three scenarios selected from summer peak week, winter peak week, and spring/fall valley week; (b) PV generation capability of three scenarios selected from summer, winter, and spring/fall; (c) market clearing price profile of three scenarios; (d) TOU rate.

TABLE II Statistics of Planning Solutions

Case No.	1	2	3
PV capacity (kW)	291.7	347.6	316.3
BESS capacity (kWh)	0.0	0.0	300.0
Controllable load capacity (kW)	250.0	250.0	250.0
Demand response capacity (kW)	0.0	64.6	127.9
Annuity cost ($/yr)	315458	314701	279942
Annual energy bill ($/yr)	236807	228912	184165
PV capital cost ($)	478388	570064	518732
BESS capital cost ($)	0.0	0.0	212400
Controllable load retrofit cost ($)	62500	62500	62500
Annual demand response revenue ($/yr)	0.0	6460	12792
Annual regulation revenue ($/yr)	0.0	0.0	7558

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Frequency regulation is considered in Case 3 to evaluate the impact of the new FERC Order 2222. Different from Case 1 and Case 2, Case 3 will invest in BESS to provide frequency regulation service. The PV capacity in Case 3 is smaller than Case 2 to limit investment cost, because the additional BESS capacity can help limit the peak load to 300 kW. Compared to Case 2, the demand response capacity is increased to maximize demand response income because both controllable load and BESS can support this service. The total investment cost of the PV, BESS, and controllable load is the highest among all three cases, but the annual energy cost of Case 3 is the lowest thanks to the lowest energy bill and the additional income of providing demand response and frequency regulation service. It is validated that DER aggregators can greatly benefit from participating in the wholesale market and providing grid services.

The results in Table II can be interpreted for an interesting outcome: load flexibility and grid service participation will drive the investment in load shifting vs. energy storage solutions. The cost of retrofitting solutions is significantly lower – and customers with more flexible loads may lean towards building automation solutions. On the contrary, commercial entities which may not have significant load flexibility may lean towards higher investments in storage based solutions for load management. Finally, for both these customers, significantly higher storage capacities can be justified by participation in regulation and other markets involving building-to-grid scenarios. Finally, with storage-only load management solutions (i.e., no load shifting from controllable load), the peak shaving capability of the customer may be severely limited. For example, if Case 1 does not have controllable load, the peak load will be higher than 450 kW even with PV and BESS invested in full capacities. Further, BESS cannot directly generate electricity to reduce the energy bill and the lack of wholesale market access may limit the return on investment for the customer. In Case 3, the BESS investment decision is made to take advantage of the economic incentives created by the market-based grid services.

C. Discussions

As discussed in Section II.A, the peak load of the building, which is of particular interest to the building aggregator and utility operator, is considered a hard constraint in the planning and retrofitting model. The peak load capacity will directly influence the planning of the commercial building. Table III compares the optimal planning solutions based on Case 1 and Case 3 with different peak load capacity limits.

TABLE III PLANNING SOLUTIONS WITH DIFFERENT PEAK LOAD LIMITS

Peak load (kW)	500	400	250
Case 1			
PV capacity (kW)	0.0	84.95	500.0
BESS capacity (kWh)	0.0	0.0	201.9
Annuity cost ($/yr)	300907	301660	345690
Case 3			
PV capacity (kW)	55.4	209.8	436.9
BESS capacity (kWh)	300.0	300.0	300.0
Demand response capacity (kW)	438.3	361.6	74.8
Annuity cost ($/yr)	262436	266784	291774

The original peak load of the building is 500 kW; thus limiting the peak load to 500 kW poses a very limited burden on the planning. Therefore, Case 1 does not invest in PV or BESS at all, and the annual energy cost is still less than the result in Table II where the peak load is limited to 300 kW. As the peak load capacity shrinks, the annual energy cost increases because some load might need have to be shifted to periods with a higher TOU rate. Case 1 needs to invest in PV and BESS to meet the peak load capacity of 400 kW and 250 kW, respectively.

In Case 3, however, BESS investment will be made with a peak load capacity limit of 500 kW to gain more profit from grid services. The demand response capacity will be reduced as the peak load capacity decreases to relieve the operational burden. As observed in tables II and III, Case 3 has a lower annual energy cost than Case 1 with all peak load capacity limits. This demonstrates that participating in grid services can help building aggregators efficiently accommodate the peak load capacity limit using DERs.

V. CONCLUSIONS

This paper proposes a planning and retrofitting model for commercial buildings to account for investment in PV, BESS, and controllable load. Peak load management and two grid services namely demand response and frequency regulation are considered in the planning model. The simulation results validate that buildings can reduce their operating costs and offset DER investments through grid services. It can be concluded that grid services and electricity market products can create profitable business solutions to accelerate DER integration, especially for BESSs which cannot generate much revenues on their own without wholesale market incentives. This also demonstrates the importance of developing such planning and operating strategies to tackle the challenges of the new FERC Order 2222.

REFERENCES

[1] U.S. Energy Information Administration, "U.S. energy facts explained," [Online]. Available: https://www.eia.gov/energyexplained/us-energy-facts/#:~:text=Download%20image%20U.S.%20primary%20energy,natural%20gas%2034%25%20petroleum%2035%25

[2] C. Chandrakumar, S. J. McLaren, D. Dowdell, et al., "A science-based approach to setting climate targets for buildings: the case of a New Zealand detached house," *Building and Environment*, vol. 169, pp. 106560, Feb. 2020.

[3] K. Horowitz, P. Zac, M. Coddington, et al., 2019. "An Overview of Distributed Energy Resource (DER) Interconnection: Current Practices and Emerging Solutions". 2019, National Renewable Energy Laboratory, Golden, CO. NREL/TP-6A20-72102. https://www.nrel.gov/docs/fy19osti/72102.pdf

[4] S. D. Nazemi, K. Mahani, A. Ghofrani, et al., "Techno-economic analysis and optimization of a microgrid considering demand-side-management," in *Proc. IEEE Texas Power and Energy Conference*, College Station, TX, USA, Feb. 2020, 6p.

[5] J. Liu, S. Cao, X. Chen, et al., "Energy planning of renewable applications in high-rise residential buildings integrating battery and hydrogen vehicle storage," *Applied Energy*, vol. 281, pp. 116038, Jan. 2021.

[6] Y. Wang, Z. Yi, D. Shi, et al., "Optimal distributed energy resources sizing for commercial building hybrid microgrids," in *Proc. IEEE Power & Energy Society General Meeting*, Portland, OR, USA, Aug. 2018, 5p.

[7] Federal Energy Regulatory Commission, "FERC Opens Wholesale Markets to Distributed Resources: Landmark Action Breaks Down Barriers to Emerging Technologies, Boosts Competition," Sep. 2020. [Online]. Available: https://www.ferc.gov/news-events/news/ferc-opens-wholesale-markets-distributed-resources-landmark-action-breaks-down

[8] California ISO, "Frequency Response Phase 2," Dec. 2016. [Online]. Available: https://www.caiso.com/Documents/IssuePaper_FrequencyResponsePhase2.pdf

[9] New York ISO, "Manual 2 Ancillary Services Mannual," Nov. 2020. [Online]. Available: https://www.nyiso.com/documents/20142/2923301/ancserv.pdf/df83ac75-c616-8c89-c664-99dfea06fe2f

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

[10] H. Zeng, F. Sun, W. Ge, A. Su, K. Gao, Y. Ge, et al., "Introduction of Australian 100MW storage operation and its enlightenment to China," in *Proc. 2018 China International Conference on Electricity Distribution (CICED)*, Sep. 2018, Tianjin, China, pp. 2895-2900.
[11] CLP (Coin-OR Linear Programming). [Online]. Available: https://github.com/coin-or/Clp
[12] Google OR-Tools. [Online]. Available: https://developers.google.com/optimization
[13] J. Cochran, P. Denholm, M. Mooney, et al., "The Los Angeles 100% renewable energy study," 2021, National Renewable Energy Laboratory, Golden, CO. NREL/TP-6A20-79444. https://maps.nrel.gov/la100/
[14] D. Feldman, V. Ramasamy, R. Fu, et al., "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2020," 2021, National Renewable Energy Laboratory, Golden, CO. NREL/TP-6A20-77324. https://www.nrel.gov/docs/fy21osti/77324.pdf
[15] California ISO Open Access Same-time Information System (OASIS). [Online]. Available: http://oasis.caiso.com/mrioasis/logon.do

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.